USER-CONFIGURABLE MODULAR PV SYSTEM WITH MICROPROCESSOR CONTROLLER.

PHASE III REPORT

DSS CONTRACT # 1SZ85-00174

Submitted by;

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February, 1987.

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Ref: USER-CONFIGURABLE MODULAR
PV SYSTEM WITH MICROPROCESSOR
CONTROL.

DSS CONTRACT # 1SZ85-00174

26 February, 1987

Dear Mr. McClung,

In compliance with contract stipulations on the above project, we hereby submit;

1. A 12-module PV Demonstration Array,
2. A Collapsible Support Stand for the Above,
3. A plastic Container for The Module Stack,
4. A Microcontroller, with Battery Charger,

and 5. A Phase III report.

It is our cherished opinion that the project was carried out to a satisfactory conclusion.

In retrospect, we thank you for kindly sponsoring the project in the first place, for continuously providing helpful advice and moral support while in progress, and consenting to the extension of deadlines when delivery difficulty was experienced. Above all, we thank you for the opportunity to demonstrate our service to the PV industry.

With best regards,

Sincerely,

N. Ismail.
President.

TABLE OF CONTENTS

Summary

Acknowledgements

		Page
1.	Objectives	1.
2.	PV System Design Improvements	2.
	2.1 Pluggable Contacts	2.
	2.2 Module Housing	3.
	2.3 Collectors	4.
	2.4 Support Stand	6.
3.	Microcontroller Packaging Improvements	7.
	3.1 Main Enclosure	7.
	3.2 Interface Box	10.
	3.3 Battery Pack	10.
	3.4 Battery Charger	12.
4.	Results & Discussions	13.
	4.1 PV System	13.
	4.1.1 Module(s)	13.
	4.1.2 3 x 4 Array	15.
	4.1.3 4 x 3 Array	16.
	4.2 Microcontroller	19.
	4.2.1 Battery Pack	19.
	4.2.2 Computer Functions	20.
5.	Conclusion	22.
6.	References	24.

LIST OF FIGURES

#	Title	Page
1.	PV Module with Pluggable Contacts	5.
2.	Array Output Collectors with Stand	5.
3.	The Collapsible Stand	8.
4.	Microcontroller Enclosure Exterior	8.
5A	Microcontroller Interior - Front View	11.
5B	Microcontroller Interior - Back View	11.
6A	Battery Charger Schematic	12.
6B	Battery Charger	12.
7.	3 x 4 PV Array	17.
8.	4 x 3 PV Array	17.
9.	V-I Output of 3 x 4 Array	18.
10.	V-I Output of 4 x 3 Array	18.

LIST OF TABLES

#		
1.	V-I Output of individual modules for EMR Array.	15.
2.	V-I Behaviour with time of the On-Board Battery Pack.	19.
3.	NOW-MAX.-MIN.-AVERAGE value of V-I Output from Array.	21.

SUMMARY

In Phase II, the following working prototypes had been constructed and demonstrated;

1. Light weight pluggable PV modules,
and 2. A microcontroller.

Although they worked well, the pluggable PV modules lacked in certain features to be attractive and suitable for mass production tooling.

The microcontroller had been developed and tested in the laboratory with the help of power supplies. That made it unrealistic for portable outdoor use. Besides, there were in our opinion too many cable connections between the different units to be a practical system.

In the concluding phase, Phase III, of the project, many corrections and design improvements to the prototypes were made, particularly with emphasis placed on self-containment, portability, cosmetic appeal, projected costs and ease of volume productions.

As a contract deliverable, a small 12-module demonstrator system was was built for EMR, contract scientific authority.

Project progress on the whole was very good for the most parts. There were helpless delays during Phase II and III due to material shipments from foreign sources, and tight scheduling or overbooking by a subcontractor respectively. We took advantage of the extra time to perform a better job.

The entire project experience is a precious one for our firm. Given the outcomes as they are, we feel confident in introducing some related new products in the near future.

ACKNOWLEDGEMENTS

First of all, our sincere gratitude is extended to Ms Pierrete Dore, Mr. Al Toren of DSS, Mr. Jack Cole, and Mr. Larry McClung of EMR for all kindly consenting to a project deadline extension because of inevitable delays on the part of a subcontractor.

Further thanks are also due to Mr. Jack Cole and Mr. Larry McClung of EMR for valuable suggestions made during their visit to our firm in September, 86. It was based on their expressed opinions that much of the improvement in the final phase of the project was made.

We are also indebted to external consultants Mr. Guy Charbonneau and Mr. Malcolm Burrill for their advice and skills in producing the array structure and the redesigned module housings.

Within our company, the dedication of staff members remained vital to a successful conclusion of this project. System engineer Bill made the necessary refinements in the microcontroller software, and succeeded in downloading the entire computer program to an EPROM to produce the intended self-contained portable system. The much improved packaging of the micro-controller, plus a complimentary battery charger for the onboard battery pack, once again demonstrated the precision skills of senior technician Peter MacFarlane, who also was the architect and builder of the PV array support stand. Our other technician Mohammed Ahmed took the challenge with grace of producing PV modules with built-in pluggable contacts, a trying assignment indeed, and resulted in a repeatable process by sheer determination.

Finally, to the many whose names have not been mentioned but whose valuable advice and assistance in the project were indispensable, we say again thank you from our hearts.

1. OBJECTIVES:

In Phase III, the final and concluding phase, of the project the objectives are as follows;

1. To improve overall PV system design.
   The PV modular housing developed in Phase II was unsuitable for mass production purposes due to its high labour content. Its weight must be reduced as well to be portable. Construction of the array was awkward, and an easier-to-deploy support frame was required.

2. To improve packaging of the microcontroller.
   The earlier microcontroller unit, though slightly smaller, had the undesirable feature of another interface box situated between itself and the PV array. That created the need of extra cable connections rendering the system awkward again. The two units should be integrated into one.

3. To build a 12-module system, test its performance, and present it with the results to EMR, project scientific authority.

4. To fully integrate the PV array and microcontroller as one system.
   The system must meet the original goal as a self-contained user-configurable energy source. In order to demonstrate that, the microcontroller will be powered by on-board battery pack, the PV modules must be readily pluggable in use, stackable when stored, and the array output closely monited by the controller.

2. PV SYSTEM DESIGN IMPROVEMENTS.

2.1 Pluggable contacts.

The earlier design in Phase II made use of contacts that were soldered to the module output leads, and had to be secured by special recess designed into the plastic housing. This entailed much work and the high cost of the resultant housing.

It was reasoned that for mass production and lower production costs, the pluggable contacts should be incorporated into the fabrication process of each module. This could be achieved by the provision of assembly fixtures that accurately position the contacts in place during the lamination step, as well as during solder reflow.

Work began in October 1986 to design such fixtures. Consultation with our subcontractors indicated that aluminum would be an appropriate material because of its excellent heat transfer properties, and resistance to soldering. As it turned out, the desired results were much more difficult to obtain than the simple use of fixtures. We went through two design iterations in the reflow fixtures, and developed a modified process in the lamination step in order to produce modules with pluggable contacts that meet requirements in registration accuracy, and mechanical strength for a minimum number of insertions and disengagements.

2.2 Module housing.

The earlier housing consisted of a top piece and a bottom piece that must be held together after the PV module had been sandwiched between. Not only this meant high labour content, but the resultant package was heavy and costly.

The fact that pluggable contacts are integral features of the module made the design of a new housing easier. No longer was it necessary to secure the contacts in the housing. The bottom piece of the housing design could also be eliminated if the module could simply be attached to the top piece, which by now would be a simple piece of plastic consisting of three essential features that can be reproduced easily and consistently by injection moulding;

1. A slightly recessed area in the middle to accommodate the module,
2. A square opening that lines up with the active area to permit the passage of sunlight,

and 3. Four simple slots that coincide with the placement of the pluggable contacts.

The module would be adhesived to the housing that involved little time and effort. To further improve appearance, if necessary, the back would be covered by a thin opaque plastic sheet to obscure the inner workings.

A sample of the PV module is shown in Fig. 1.

2.3 Collectors.

We had used window frame aluminum channel material in our earlier design for the array output collectors. That involved a lot of drilling of holes. In order to secure firm contacts with the modular strings, we also resorted to the use of rubber sections slipped over wooden dowel rods for pressure fits. In all that was not a cost effective approach.

The new collectors are plastic pieces that can be mass produced by injection moulding. Each collector consisted of a relatively simple top piece. The only machined feature in this part is the square well at one end for the output pin jack. This same piece can be used for either the +ve or -ve collector.

The bottom pieces of the +ve and -ve collectors are same in outer dimensions, but differ in interior details demaned by the differences in shape and positioning of the + and - contacts. The +ve collector have - contacts that were all recessed within the collector , whereas the -ve collector possessed + contacts that protruded above the surface by ½".

Each collector was 21" long and contained 8 contacts positioned to accept 4 strings of modules (for the EMR demonstration system). Five self-tapping screws were used to secure the top and bottom pieces together along its length.

A jumper wire connected all the contacts within a collector and the collective output was tied to the output pin jack at the end.

The Output collectors, together with the support stand, is shown in Fig. 2.

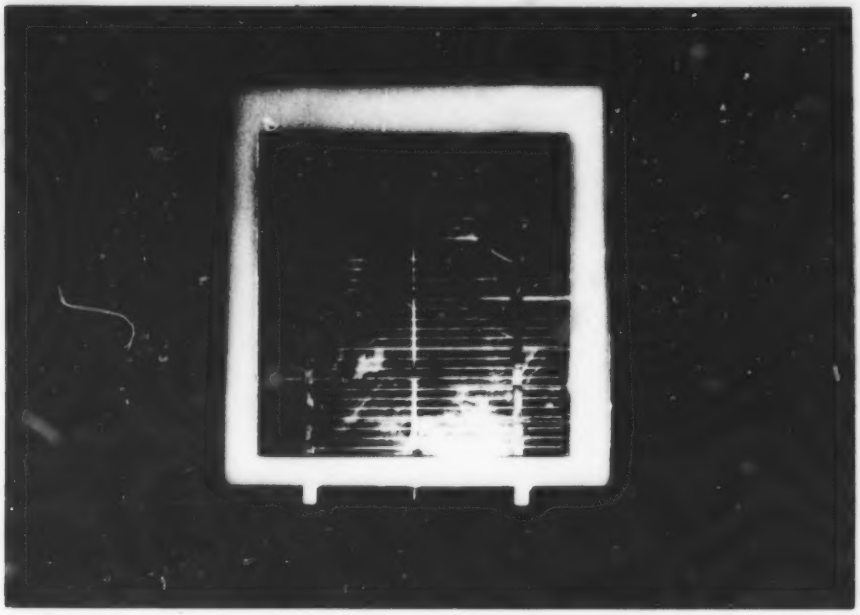

Fig.. 1. PV Module with Pluggable Contacts

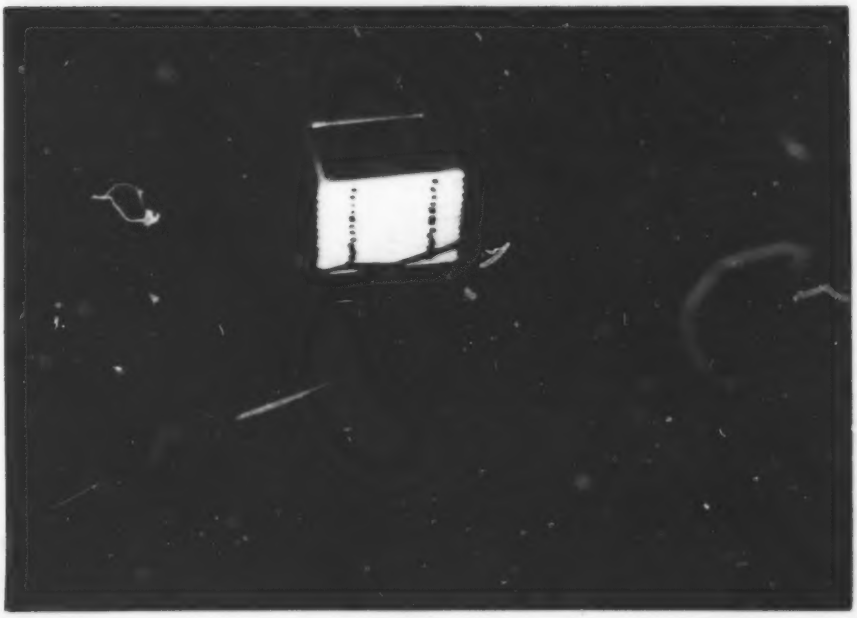

Fig. 2. Array Output Collectors with Collapsible Stand and Stacked Modules.

2.4 Support stand.

Testing of the PV arrays built in Phase II had been done by leaning them on a retort stand, or other similar object for support. To be self-contained the final system obviously needed a support stand of it own.

Our design effort began with the concept of a collapsible frame which not only must contain the modules in use, but also a means of holding the solar photometer-charger as an appendage. The structure must also be light weight, yet rugged enough, and not expensive to produce.

After much deliberation, we finally selected the use of long aluminum sheet metal members in combination with pop rivets and wing nuts that could be tightened and swiveled at the joints. This construction satisfied the light weight and low cost requirements. To adjust the tilt angle, we used a 15" long-3/8" diameter wooden dowel rod at the back with a swing movement at the top which is hinged to the middle of the upper frame. Swing movement in the direction outside the plane of the array was provided by two right-angled aluminum brackets riveted together.

The solar photometer-charger was located at the lower portion of the frame by a swinging side arm that carried two spring clips. The photometer could be secured by the spring clips during testing solar insolation.

To further facilitate the use of the support stand in outdoor terrains, rubber feet were added to the areas that would make contact with the ground to prevent slippage. The entire design bears a close resemblance to a music sheet stand, but turned sideways. Fig. 3 shows the stand in a deployed position.

3. MICROCONTROLLER PACKAGING IMPROVEMENTS.

Earlier emphasis in the development of the microcontroller during Phase II was in demonstrating performance. To make it easier for trouble-shooting in the event of problems, we had built the computer unit separate from the interface sensing unit. That proved to be a good choice as we indeed had to analyse and rectify each unit on several occassions. As a total system for portable situations, it became highly desirable to combine the two into one.

3.1 Main enclosure.

Our first task was to seek a larger metal box that would contain all necessary components, be strong enough to withstand portable treatments, and yet attractive at the same time. We found such a box,

The metal box used had heat vent grill in the back to maintain interior temperature reasonably low. It had a nice matt coating of blue paint on the top and the two ends. The front side, where the LCD display panel and the red control keys would be mounted, was painted black. The red buttons contrasted nicely against the black background.

The material was thick gauge aluminum which should be able to withstand a few accidental drops from waist height, yet not too difficult to drill through for mounting holes. The left side of the box was used for this purpose exclusively. Two control toggle switches were mounted near the front for easy access. A VDT power jack for the solar photometer-charger was located in the middle. The power-in (from the PV array) and power-out (to the load or battery) jacks were at the back. See Fig. 4.

The front side carried the LCD display across the top portion. The little red RESET button was to its right. The ten large red functional keys were evenly spaced out below the LCD display in two rows of five.

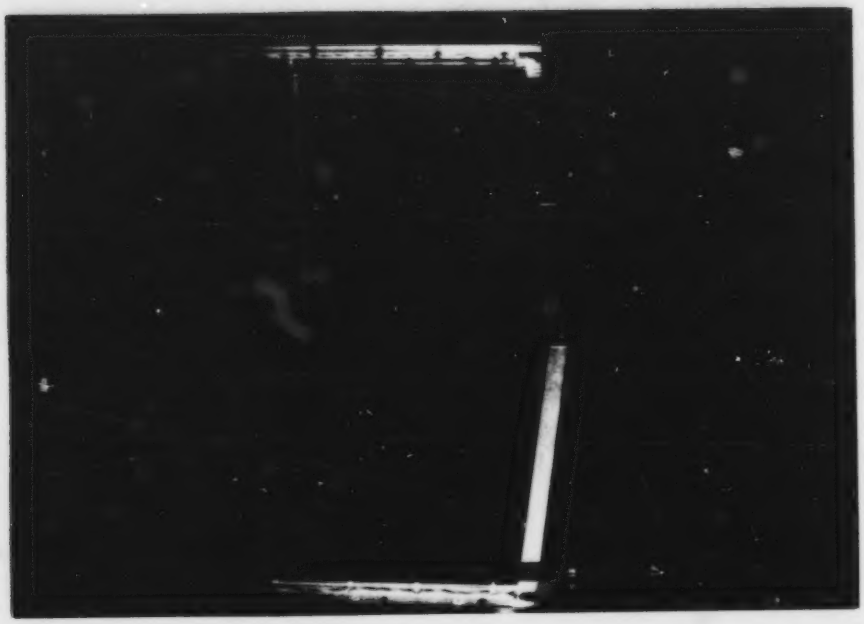

Fig. 3. The Collapsible Support Stand.

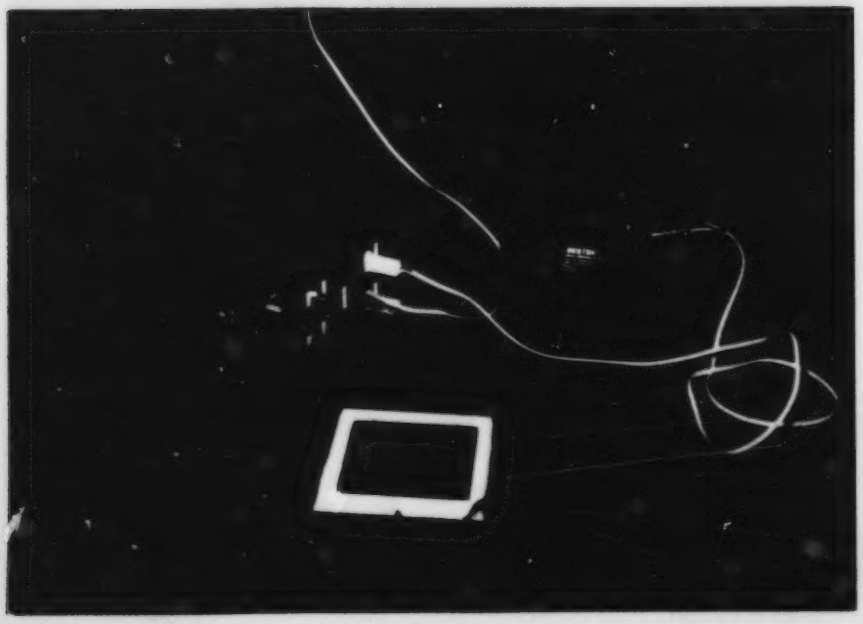

Fig. 4. The Microcontroller Enclosure Exterior.

The interior of the enclosure was densely packed with components from side to side. The left wall was occupied by the five items mentioned above. The right wall was taken up by the interface box that is described below.

In the middle of the enclosure are the three printed circuit board stacked one above the other. At the bottom would be the Z80 CPU computer board. In the middle was the A/D converter board with the EPROM chip that contains the Bestek developed software. At the top was the smaller interface board with the 5V-+/- 12V DC/DC converter.

To the left of the PCB stack would be the battery pack for powering the controller.

Interconnection between the boards was provided by 44-pin cardedge connectors. Other incidental connections, eg. to switches, LCD drivers, etc. were achieved with smaller ribbon cables and Molex type connectors.

Fig. 5A shows the interior of the controller taken from the front. Fig. 5B shows the interior taken from the back clearly illustrating the LCD display unit with its integrated driver electronics.

3.2 Interface box.

This unit senses the PV array output power and sends control signals to the A/D board which in turn interprets them for the CPU for controlling and displaying purposes. Structurally it did not differ very much from its earlier counterpart developed in Phase II. The most critical element within this box is the ferrite toroid wound with over 200 turns of # 22 wire, through which the output current flows thereby creating magnetic flux within the toroid. A Hall cell placed in the path of the magnetic flux would generate a small voltage that corresponds to the amperage of the current flowing in the coil.

With careful placement of parts, we were able to cramp all vital components on a small printed circuit board and housed it inside a 1½" x 2½" x 4" metal box. The interface box was mounted on the inside wall of the main enclosure as an integral part of the control system. It can be seen as the grey unit in Fig. 5A and 5B with white power cords coming out at both ends.

3.3 Battery pack.

This is the on-board power source that runs the micro-controller. For weight and size considerations, we chose to use 4 C-size nickel cadmium type batteries of 1.4AH capacity each. Held together by a plastic battery holder, the entire pack weighed in at 250 gms.

The four batteries in series delivered 5V which was ideal for the CPU computer boards, and the DC/DC up converter to +/- 12VDC voltages for operating the op. amps. The recommended charge current was 100 mA for 14 hours, which also agreed well with the output of the solar photometer-charger.

The four batteries were purchased from Radio Shack and can be seen as the purple group in Fig. 5A and 5B.

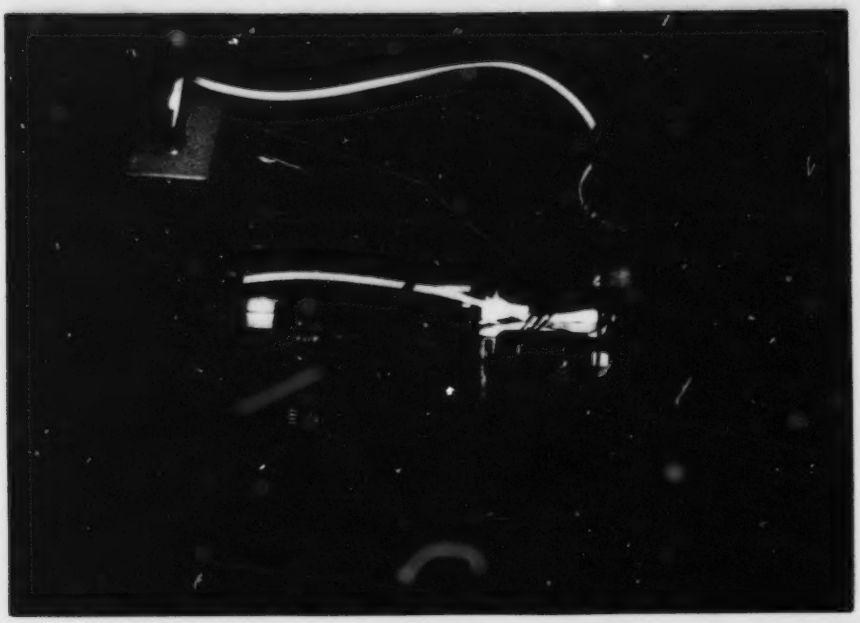

Fig. 5A. Microcontroller Interior - Front View

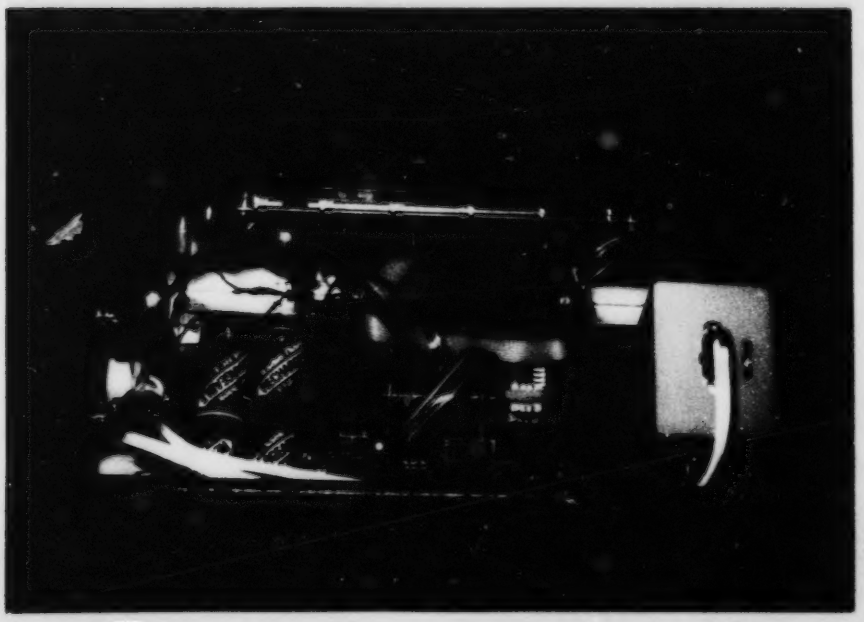

Fig. 5B. Microcontroller Interior - Back View.

3.4 Battery charger.

The microcontroller on-board battery pack mentioned earlier is a finite power source. When fully charged it would operate the system for about 1½ hour before its functions become unreliable. The charging action of the solar photometer-charger will extend this time duration marginally due its limited (100 mA) output. This situation is the result of the large amounts of TTL logic employed in the computer boards that consume power. If CMOS version were used, the 100 mA would likely be more than adequate.

To maintain top charge in the battery pack and be ready for action, we designed and built a simple battery charger that is shown below. Fig. 6A is the electrical schematic, and Fig. 6B is the actual unit.

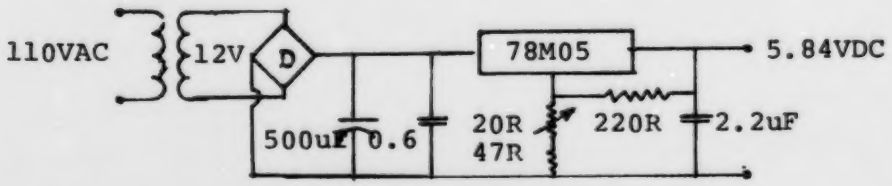

Fig. 6A Battery Charger Schematic.

Fig. 6B Battery Charger.

4. RESULTS AND DISCUSSIONS.

4.1 PV System.

4.1.1 Modules.

Weight reduction:

The earlier module developed in Phase II weighed 190 gms. It consisted of a top and a bottom piece that sandwiched the PV device in between.

The new module weighs only 65 gms. It had only a top frame to which the same PV device is glud.

The weight reduction is therefore 125 Gms., or 66% of the original.

Size reduction;

The earlier module measured 5.4" x 5.9" x o,38" when assembled.

The new module measured 5" x 5.1" x ¼" and had a pleasing 30-degree slope on the two sides.

The area reduction, therefore more compact, is equivalent to (31.86 - 25.5) sq.in, which is 6.36 sq.in., or 20% off the original size.

The thickness reduction would be (0.38" - 0.25") which is 0.13", or 34% savings in stack height when a number of modules are stacked on top of one another. Consequently a 12-module stack comes only to 3" tall instead of the 4" that otherwize would have been.

While we were pleased with the weight and size reduction, we also became concerned with the mechanical strength of the module. It was decided that a plastic pin be added between the male (+ve) contacts, and correspondingly a hole between the female (-ve) contacts, the purpose being that

it would provide reinforcement and help alignment when plugging the modules together. This did not, however, yield the desired result perhaps because of the workmanship involved in the pin fabrication. The sloppy placement of the undersized pins in the slightly bigger holes produced poor registration. When the modules were connected together, the pins created additional difficulties rather than aid the operation. Some even broke off from the strain experienced. The experience does not rule out the possibility though that the scheme might work well with injection moulded parts that usually have better dimensional tolerances.

In setting up a PV array, we discovered that the modules could come loose as easily as they were connected together. This was particularly true when the collectors were being added on to the ends of the modular strings. A possible remedy to the problem would be a more positive engagement force between modules that are connected. This could come either from contacts that have a much tighter friction fit, or some mechanical means with a locking force.

The 30-degree slope on the two sides made the module more attractive, and easier for the fingers to fit in between modular strings when assembling the array. In terms of mass production of these housings by injection moulding method, the sloped faces would also help the release process at the end of the injection cycle.

4.1.2 3 x 4 Array.

A condition of the project was to produce a 12 module system for EMR, the scientific authority. Each module in this case would consist of 8 segments that were electrically connected in series, referred to as NSG-8. The following is a summary of the V-I output of 12 such modules chosen for the system.

Table 1.

Module #	Voc	Isc	V22R	I22R
1	4.93V	154 mA	3.3V	106 mA
2	5.0	220	4.25	145
3	5.07	206	4.42	147
4	5.0	185	4.18	138
5	4.85	180	3.55	120
6	4.9	190	4.2	133
7	4.93	195	4.3	138
8	5.09	157	4.22	140
9	4.7	190	3.6	114
10	4.87	191	4.0	124
11	4.92	171	4.0	136
12	4.75	214	4.11	135

The Voc and Isc refer to the open circuit voltage and short circuit currents when pointed at the sun. The V22R and I22R values were obtained when a 22-ohm resistor was added across the output to simulate a load at the maximum power point, which indicates roughly if the unit has a reasonable fill factor (FF).

These modules were then connected into a 3 x 4 format and secured on to the array support stand. See Fig. 7. The V-I output of the array was measured and shown in Fig. 9.

As can be seen from the results (Fig. 9), the array had a Voc of 14.4V and an Isc of 0.76A. The Pmax occurred at 11.6V and 0.57A, or 6.6W. The fill factor is therefore (6.6/10.9 x 100%), or 61 %. All measurements were done with recently calibrated Fluke 75 multimeters and would be accurate to within 5%.

We would have preferred to see a higher fill factor perhaps in the 70% range. Taken into account the number of pluggable contacts involved, plus the looseness of the contacts mentioned before, we found the 61% not entirely unreasonable altogether.

4.1.3 4 x 3 Array.

The above 3 x 4 array was taken apart, and the 12 modules were then reconfigured into a 4 x 3 format. See Fig. 8. The V-I results were taken and shown in Fig. 10.

As can be seen from the results (Fig. 10), the array had a Voc of 19.4V and an Isc of 0.63A. The Pmax occurred at 15V and 0.53A, or 7.95W. The fill factor is therefore (7.95/12.2 x 100%) or 65%. This is a small improvement over the other array, due perhaps to better matching of modules in each string. The real significance is in its consistency between two individual set-ups using the same modules.

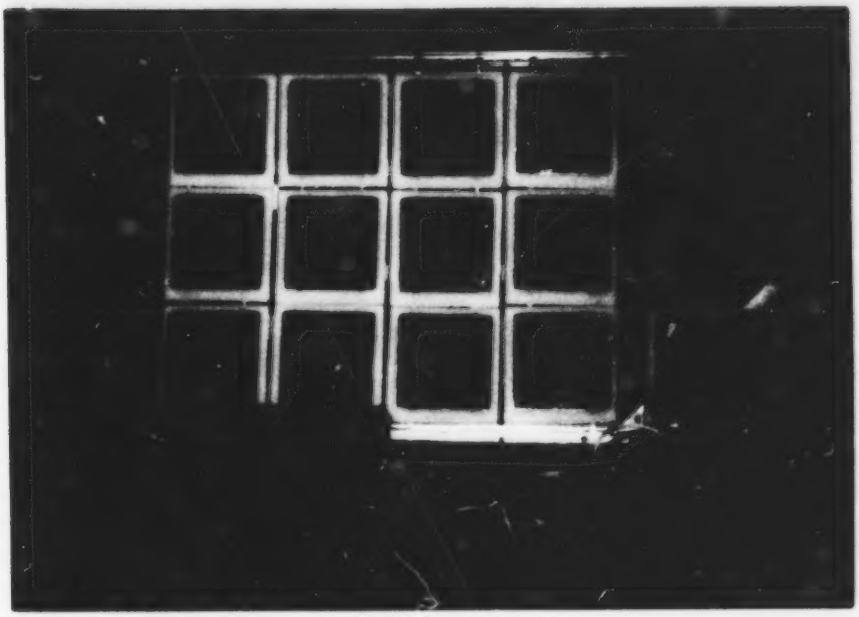

Fig. 7. 3 x 4 PV Array

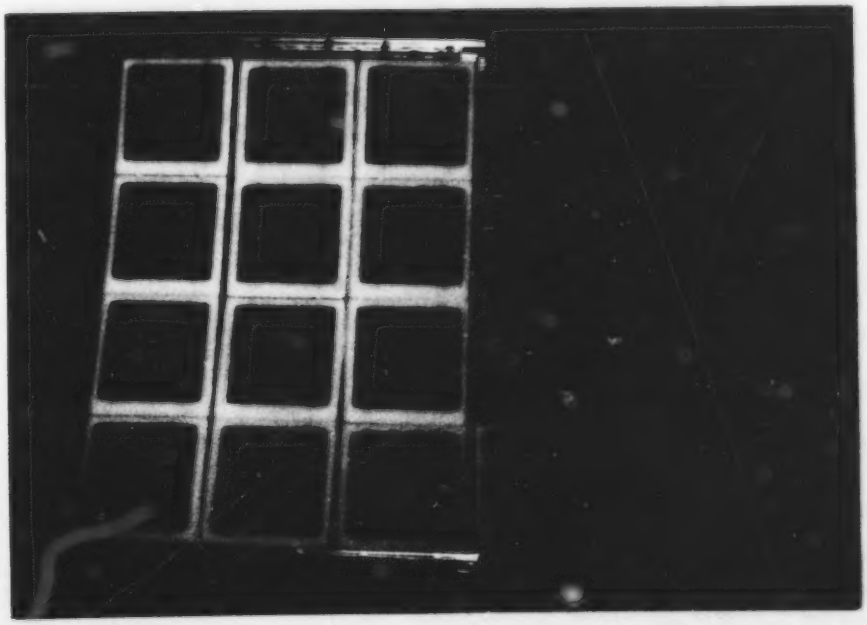

Fig. 8 4 x 3 PV Array.

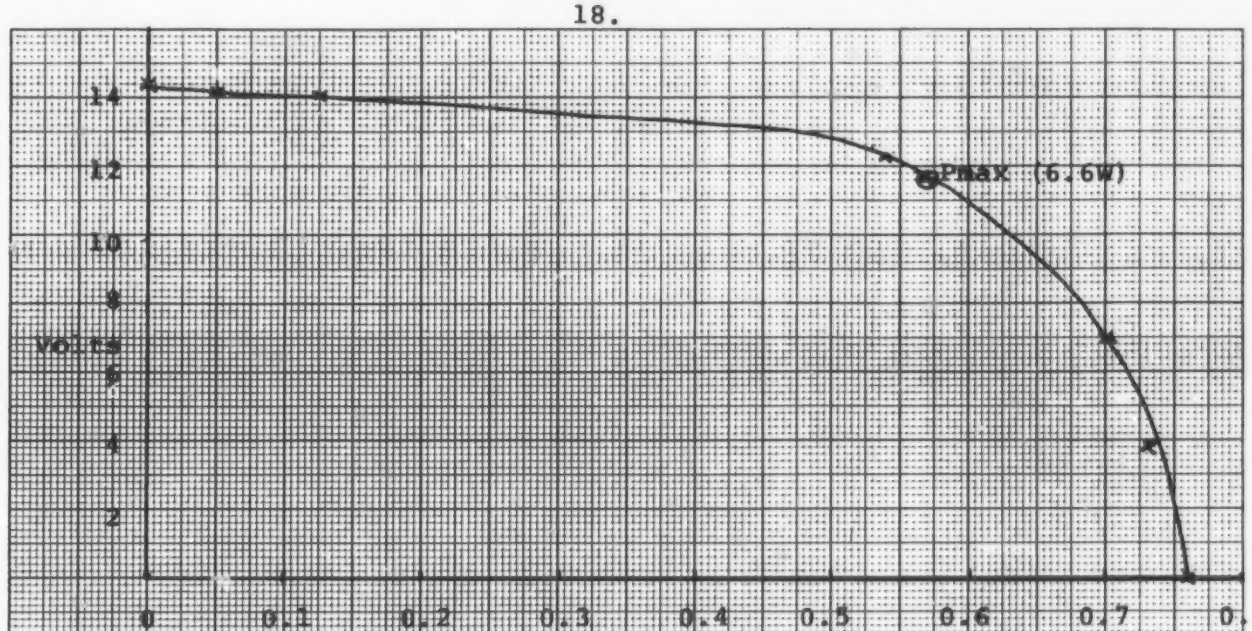

Fig. 9. V-I Output of 3 x 4 Array.

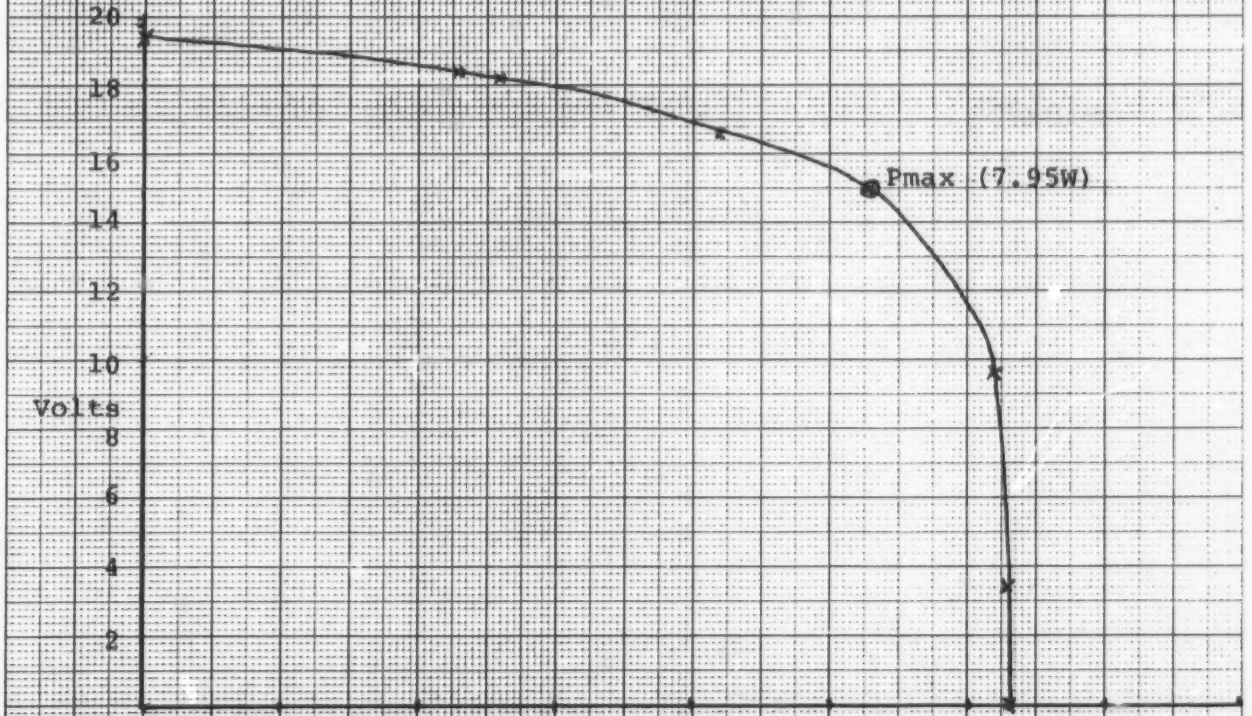

Fig. 10. V-I Output of 4 x 3 Array.

46 1510
K+E 10 X 10 TO THE CENTIMETER 18 X 25 CM.
KEUFFEL & ESSER CO. MADE IN U.S.A.

4.2 Microcontroller.

4.2.1 Battery pack.

In selecting the 4 C-size NiCd batteries for the on-board power source, we needed to establish how long they would sustain operation on a full charge. We began by deliberately discharging all batteries to a very low point. They were then recharged at the recommended 100 mA for 16 hours to bring them back for full charge. After returning them to the micrcontroller, we began timing its behaviour while powering the system by monitoring its output current and voltage. The results are as follows.

Table. 2.

Time	Voltage	Current Drain
0 min.	5.07V	470 mA
5	4.9	440
10	4.85	430
15	4.81	430
20	4.79	430
25	4.78	430
30	4.77	430
35	4.77	430
40	4.76	420
45	4.75	420
50	4.75	420
55	4.74	420
1 hr.	4.72	420
1:05	4.70	420
1:10	4.68	420
1:15	4.65	420
1:20	4.60	420
1:25	4.55	420
1:30	4.49	420
1:35	3.14	390

4.2.2 Computer functions.

The computer in the microcontroller was designed to perform the important functions of;

1. System configuration calculations,
2. System output monitoring, and
3. As an aid in diagnostic in case of failure.

Configuration.

The computer was put to test by being asked to configure a system using NSG-8 modules to provide 9V and 700 mA at the output. After following the question-answer procedure guided by the computer instructions, it gave the following;

3 NSG-8 Modules per string.
5 Parallel strings.

In reviewing the output of the 3 x 4 array (Fig. 9), we found the computer calculations accurate to within 1 string. This is perhaps due to the fact that the computer is instructed to round off to the nearest higher integer in string calculations.

We repeated the exercise by asking the computer to configure a system using NSG-8 nodules again that would yield 12V and 600 mA at the output. The computer returned with the following answer;

4 NSG-8 Modules per string.
4 Parallel strings.

By looking at the output of the 4 x 3 array (Fig. 10), it can be seen that the design calculations were correct again in the number of modules per string, but one string too high in the number of parallel strings, due perhaps again to the above reason.

In practice, we would rather err on more strings needed than not enough string of modules to perform the job adequately. In this regard, the computer is playing it safe and, therefore, acceptable.

Monitoring.

As a system monitor of V and I values, the computer was designed to display instantaneous values, record and update Max. and Min. values continuously, and calculate averages as time progresses.

The 4 x 3 array was set up to charge a 12V lead acid battery in a relatively clear sunny afternoon with the following result within 30 minutes;

Table 3.

Time	Now		Max		Min.		Average.	
(min.)	V	I	V	I	V	I	V	I
0	17.2	0.33	17.6	o.36	17.0	0.32	17.0	0.32
10	17.6	0.36	19.9	0.39	17.0	0.10	17.3	0.30
20	17.6	0.33	19.9	0.39	17.0	0.10	17.3	0.30
30	17.6	0.28	19.9	0.39	17.0	0.10	17.4	0.27

In studying the above data, it can be shown that the NOW values of both V and I did vary with each time a reading was taken. The MAX. values however kept increasing or stayed at the previous high at least, therefore in fact recording the highest readings and retaining them in memory until exceeded by a new MAX. In a similar but opposite manner, the MIN. values kept decreasing in values or at least stayed at the previous low. It therefore is also performing as expected. The AVERAGE values seemed to vary up and down a bit, reflecting a dynamic behavious which is indicative of its truthful operation.

These types of data, when retrieved at the end of a mission, could shed light on the solar charger behaviour during the entire operation, and are also useful for estimating the amount of energy processed.

Diagnostics.

The diagnostic capability of the controller consists of;

1. Detecting a weak string,
and 2. Detecting a defective module.

Weak String Detection.

The basic assumption used in an array made up of parallel strings is that all strings contribute equally, within a small percentage of deviation. In testing the system capability, we used the 3 x 4 array of Fig. 7.

While monitoring the Vnow and Inow values, we successively blanketed out the strings one at a time from left to right. This did not affect the Vnow reading in any way, but the Inow value dropped to between 70 - 80% of its full value each time a string was covered. This was suffcient evidence that all four strings were equally responsible for the total output.

Defective Module Detection.

The basic assumption here is that a weak module impedes the current flow within a string. Is removal, or bypass by an external short, should return full string current. This operation, however, necessitates the removal of all other strings after the weak string, wherein the defective module resides, has been isolated by the above mentioned method. In practice, we found this to be cumbersome and not too effective. As it turned out, it was easier to remove the weak string and identify the bad module by either visual inspection, or simple electrical testing one module after another.

5. CONCLUSION

Bestek Micro Devices & Systems Inc. of Ottawa has successfully designed, constructed, and tested modular PV systems with microprocessor controls. The work, carried out from February 1986 to February 1987, was made possible only by the financial generosity of the federal department of Energy, Mines and Resources.

There are three essential components to the integrated system, viz.

1. Pluggable PV modules,
2. A collapsible support stand,

and 3. A microcontroller.

Apart from facilitating simple interconnections, the light weight plastic pluggable modules offer portability, stackable storage, inexpensive mass production, and above all remove restrictions on the size and format of the array to be built. The absence of glass in their construction also contributed to their ruggedness.

The electronic microcontroller was developed as a helpful adjoint. To the PV ṅninitiated, it acts as a user-friendly instructor in determining the the array that is required by a given mission. To the experienced user, it becomes a manipulative tool for data storage and trouble-shooting, if necessary, in a short time.

The project was prompted by our observation of a trend towards portable systems in the PV industry. As a result of this work, it is now possible (for the first time) to generate solar power in reasonably powerful ranges (eg. 10W) over a wide range of circumstances. This added capability will hopefully be beneficial to the PV industry at large, and particularly to Canada as the originator. As corporate partner in the project, our effort will be relentless in the commercialization of the technology developed.

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